

HIGH VOLTAGE SUBNANOSECOND CORONA INCEPTION

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Abstract

Corona Discharges in Ultra-Wideband radiating systems can have adverse effects on performance such as reflection, phase dispersion, and significant power losses. A test-bed has been assembled to experimentally observe corona created by voltage pulses similar to Ultra-Wideband systems. The current work involves the voltage attenuation of an incident pulse after propagation through a self-initiated corona and relative measurements of visible light emission from the photoionization produced during streamer development. Several gas dielectrics, including ambient air, N_2 , H_2 , and SF_6 , were tested.

I. INTRODUCTION

High Voltage Ultra-Wideband (UWB) radiating systems can produce pulses greater than 1 Megavolt with risetimes less than 100 picoseconds (ps), pulsewidths of several hundred ps, at repetition rates as high as several kHz. Under certain conditions, an undesirable side effect during operation is the establishment of corona. The corona may arise in any or all of three sections of the UWB system, the transmission line between the main switch and the antenna, the antenna itself, and the region in front of the antenna. Corona within the system can have adverse effects such as attenuation of the main pulse caused by the streamer current feeding the corona. Attenuation of the main pulse is observed in the far field at the higher repetition rates. This attenuation is believed to be a result of corona.

Previous work on positive pulsed corona has been on the pre-breakdown or primary streamer development in point-plane electrode geometries [1,2]. Primary streamer onset time was on the order of tens of nanoseconds. Prior work on primary streamer development in less than a nanosecond is either non-existent or very scarce.

The aforementioned experiments were a single pulse corona phenomenon. In an UWB environment, the influence of a previous discharge on the development of a discharge is of extreme importance. The presence of

residual ions and neutral excited species has a strong influence on corona discharges [3]. It has been observed from spectroscopic measurements that a significant number of metastable species are produced during repetitive discharges, increasing in number with increasing pulse frequency [4]. These metastables can be easily ionized, which will affect the development of succeeding discharges.

The current effort was initiated to observe the production of corona under the application of UWB type voltage pulses. Gas pressure ranged from ten to hundreds of Torr. The voltage amplitude applied was two orders of magnitude lower than what would be found in a Megavolt UWB system. However, we believe the data gathered should scale directly with E-field / Pressure (E/P). Gases examined were air, N_2 , H_2 , and SF_6 . Air was chosen since eventually, the radiated UWB must propagate through air. SF_6 is sometimes used within the system, usually encapsulated in a bag, to prevent breakdown and corona. N_2 was chosen as a diatomic gas with properties similar to air, also N_2 is often used in admixtures with SF_6 . H_2 is an easily ionized gas, which would provide a comparison to the other gases.

II. EXPERIMENTAL APPARATUS

The pulsed power supply is a solid state device capable of producing ultra-fast, 10 kV pulses into 50 ohms at repetition rates varying from 0.1 to 6 kHz. The pulse risetime is less than 200 ps at a pulsewidth of 700 ps FWHM.

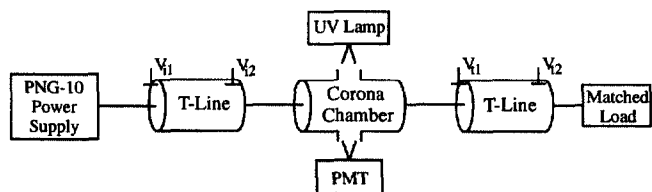


Figure 1. Schematic diagram of the pulsed corona system.

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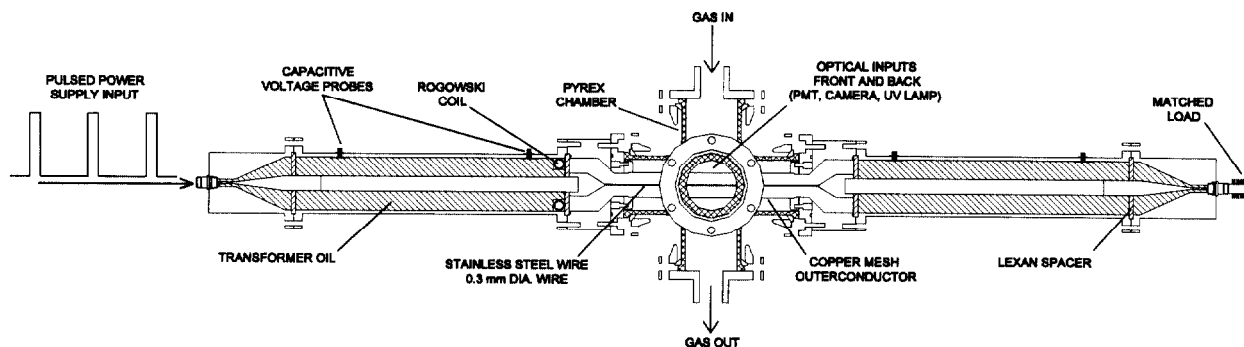


Figure 2. Cross-sectional view of the pulsed corona system. The placement of diagnostics is indicated.

The capacitive voltage probes, V_{ix} and V_{tx} , are very fast and capable of responding to the ultra-short risetimes of the pulsed power source [5]. Incident and transmitted voltage signals from the corona chamber are recorded with a Tektronix SCD5000 transient digitizing oscilloscope. The photomultiplier, PMT, is a Hamamatsu R1894 with a response time of 0.8 ns.

Figure 2 shows a cross-sectional view of the overall system. The input of the system is a type-N connector that transitions to a 3", 50 ohm, oil-filled transmission line. The lines allow for the use of capacitive voltage probes and have an electrical length of approximately 4.5 ns. The corona is produced within the Pyrex chamber along a 0.3 mm dia., 12" long, stainless steel wire. The outer conductor in the chamber is made from 3 mm, copper mesh, necessary for optical diagnostics. The corona chamber has a characteristic impedance of 290 ohm. The average E-field in the chamber is 9.4 kV/cm with an enhanced E-field at the wire of 118 kV/cm. An Ultra-Violet lamp is used to pre-ionize the chamber for all data except for PMT results.

III. EXPERIMENTAL RESULTS

The electrical characteristics of the corona chamber were measured via capacitive voltage probes on either side of the chamber. The probes provided incident and transmitted voltage waveform information. Figure 3 shows typical voltage waveforms taken in N_2 at 200 Torr.

Shown in figures 4 and 5 is the peak power transmitted through the chamber for various gases and pressures at a repetition rate of 500 Hz. As the pressure is changed for an individual gas, the amount of power lost to corona varies. The statistical variation between individual shots was minimal.

Figures 6 and 7 show the total energy transmitted through the chamber for various gases and pressures. The energy is taken from the main pulse, disregarding reflections, from the moment of arrival to 4 ns later. The energy in the incident pulse to the corona chamber is 1.2 mJ.

Another influence on transmitted peak power is the source repetition rate. Figure 8 shows transmitted peak power in air at various pressures for three different

repetition rates. Obviously, as the repetition rate increases the transmitted peak power decreases.

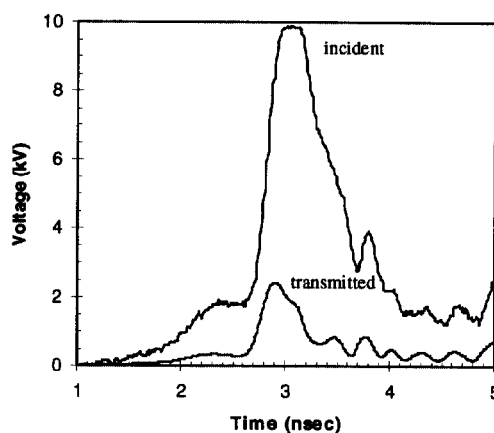


Figure 3. Typical voltage waveforms incident to and transmitted through the corona chamber. Taken with N_2 at 200 Torr at 500 Hz.

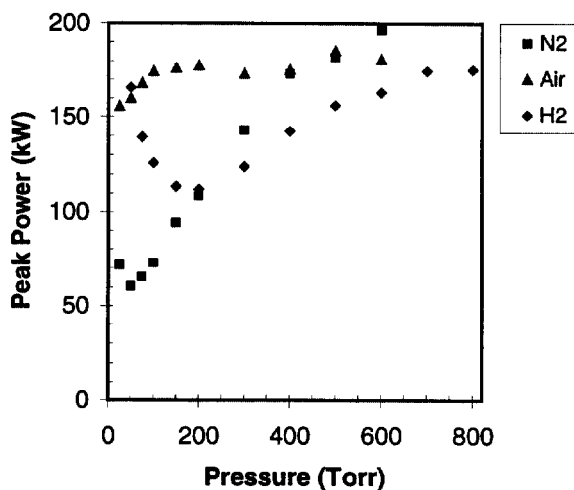


Figure 4. Transmitted peak power through the corona chamber at various pressures for several gases at 500 Hz repetition rate.

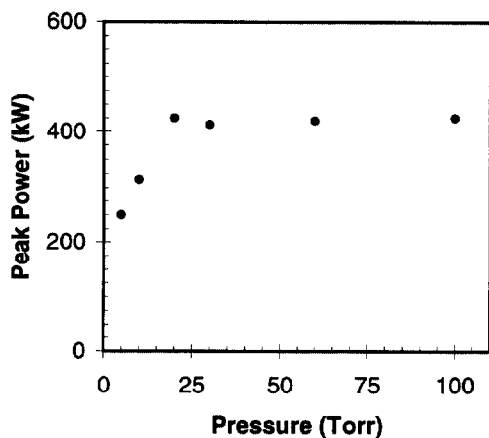


Figure 5. Transmitted peak power through corona chamber in SF_6 at various pressures and a repetition rate of 500 Hz.

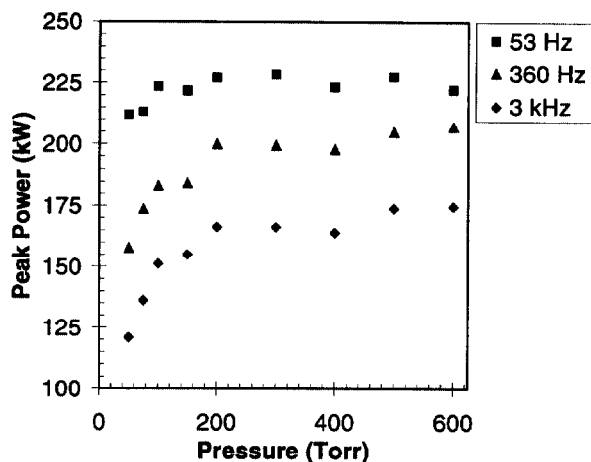


Figure 8. Transmitted peak power through the corona in air at various pressures and repetition rates.

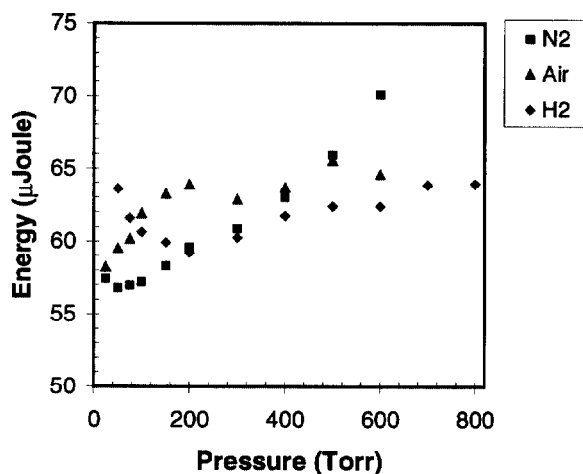


Figure 6. Total energy of the main pulse transmitted through the chamber at various pressures and gases at 500 Hz.

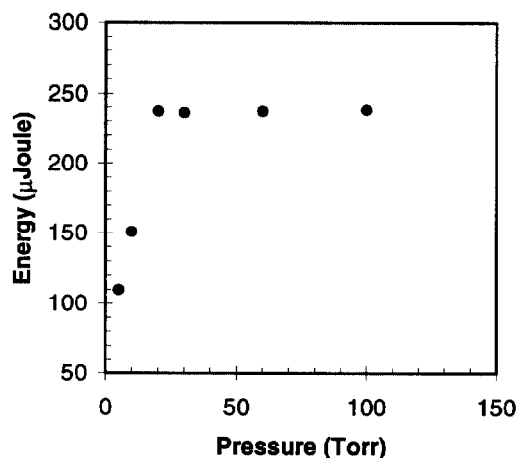


Figure 7. Total energy of the main pulse transmitted through the chamber at various pressures of SF_6 at 500 Hz.

Information on the photoemission from the corona was obtained with a fast response photomultiplier. Observations were attempted with an ultra-fast photodiode, however the light emitted by the corona was too faint. Figure 9 shows typical photoemission waveforms in N_2 at various pressures. Figures 10 and 11 show peak photoemission in various gases and pressures. Using a photomultiplier did not allow for the use of an UV lamp shown at the chamber. This increased the statistical variation between shots therefore, one-deviation, error bars for a sampling of 10 shots per data point are shown.

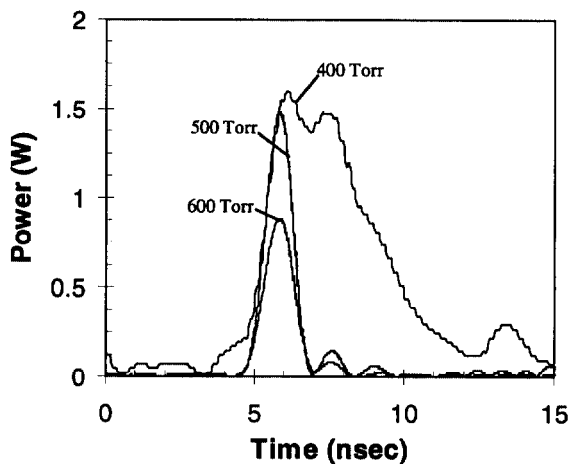


Figure 9. Typical PMT waveforms generated by photoemission of corona in N_2 at various pressures and 500 Hz.

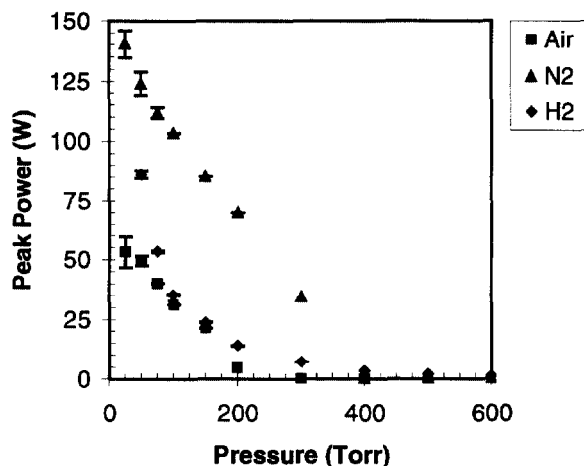


Figure 10. Peak photoemission power generated by corona in various gases and pressures at 500 Hz.

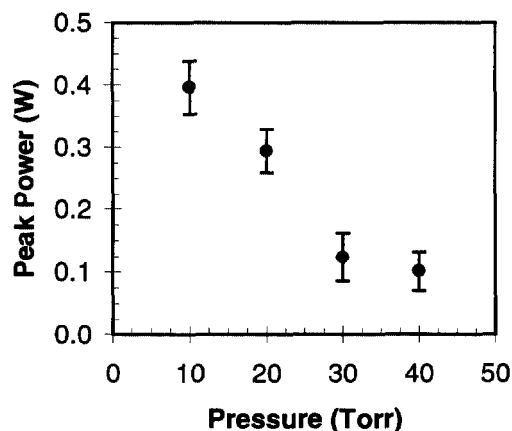


Figure 11. Peak photoemission power generated by corona in SF₆ at various pressures and 500 Hz.

IV. DISCUSSION

The above results serve as a baseline for further improvements in the performance of UWB systems. Ideally, the data would have been obtained at a higher applied voltage and pressure. However, being limited to the 10 kV source, it was necessary to experiment at lower pressures, since at high pressures (one atmosphere) and above, corona production was too small. Fortunately, the observed data scales with E/P. Therefore, data can be used in the higher voltage UWB systems.

Several interesting observations can be made from the data. The transmitted peak power in N₂ and H₂ is nonlinear with respect to pressure, with minimums at 50 and 200 Torr, respectively. The minimum transmitted peak power in Air and SF₆ occur at the lower pressures. One would expect that as the pressure of these gases is decreased, the transmitted peak power would begin to increase.

The photoemission from the corona at low pressure is seen to continue at much longer times than the applied pulse, as shown for N₂ at 400 Torr in Figure 9. This is a result of the longer recombination times at the lower pressures and of the voltage pulse reflections between the chamber and source. These reflections are unwanted but unavoidable. One would, however, also expect to see similar reflections within an UWB system since the source and load (or antenna) will never be exactly matched.

Perhaps the most interesting observation is the transmitted peak power dependence upon repetition rate (Figure 8). One observes a 25% drop between 53 and 3 kHz. This is most likely due to an increased number of metastables at the higher frequency.

V. CONCLUSIONS

Corona phenomena have been observed in the UWB regime for several gases. Points of interest include corona development dependence on gas pressure and repetition rate and the lifetime of corona dependence on pressure and pulse reflections. It is hoped that observations will provide valuable information in future UWB system developments.

VI. ACKNOWLEDGEMENTS

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